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How to Determine Altitudes Satisfactorily With an Aneroid Barometer.

J. E. TODD.

The purpose of this paper is to give a few simple rules by the observance of which the local influence of the weather and other temporary conditions may be eliminated and the normal pressure of the atmosphere at that point be definitely determined. The difference in the normal or average atmospheric pressure at two points will give their difference in altitude.

There are three fields in which the aneroid is an almost ideal instrument:

1. The determination of the height of mountains and other points in a mountainous region. These are miles apart and vary thousands of feet in height. An admirable plan for the use of the aneroid in such a field was devised by Gilbert years ago and was published in the second annual report of the United States Geological Survey, page 403 *et seq.*

2. The ascertaining of altitudes in regions of low relief, hilly and plains areas. The differences in altitudes between adjacent points are from a few

feet to a few hundred only. The determination of gentle dips or of low anticlines and other "structures" employ similar means and methods. Such cases may therefore be grouped in this class.

3. The third use of the aneroid is to give the altitude of aëroplanes. This, so far as the writer is aware, has not been critically studied, and besides has very little to do with geology.

Our discussion will be particularly of the second field, in which the writer has had more than forty years' experience, mostly on the great central and western plains.

Believing that this handy instrument has been misinterpreted and underrated by many, this paper attempts to correct these errors.

CAUSES OF BAROMETRIC VARIATIONS.

These may be grouped, for convenience, under three heads, viz.: First, influences of the weather; second, peculiarities of the instrument; and third, peculiarities or errors of the observer. Weather influences are real and much the most important. The others must not be ignored, though effects are more apparent than real.

WEATHER INFLUENCES.

1. *Expansion of air by heating.* This heat comes from the sun, and practically all of it is imparted to the atmosphere at the surface of the earth. When the sun shines after darkness or after a cloud has passed, it heats the earth, which by contact and convection heats the layers of air just above. This tends to expand it, but the superincumbent ocean of air resting upon it prevents. In time, however, the heating is sufficient to overcome the weight, inertia and friction of the upper air. We may suppose the surface of the atmospheric ocean is locally raised in a broad hummock. This will rise till gravitation causes currents of air to lower areas of the atmospheric ocean. This will reduce downward pressure over the heated area.

Meanwhile the barometer will rise until the superincumbent air begins to give way, when it will fall while the disturbing factor acts. It follows that days when clouds float across the sky have a very unsteady barometer. It is hardly worth while to use the barometer unless it is your only chance.

2. *Aqueous vapor.* This is lighter than air and readily mixes with it. The capacity of the air to absorb it increases with the temperature, but much more rapidly and irregularly. Its general effect is to simply magnify the effect of the preceding.

3. *Wind.* For convenience, we consider this as a separate cause, though really it is a particular effect of cause one.

The pressure of the air will remain about the same when the air is unheated and still, but in case it is moving rapidly horizontally it will tend to increase the density of the air on the windward side of objects, either a cliff, a house, or even the body of a person, and to decrease the density and pressure on the lee side. The harder the wind is blowing the greater is this effect. Not infrequently the barometer may read the difference of two or three hundredths of an inch on opposite sides of the body at the same level. Another anomaly is that when the wind strikes against a precipitous cliff or the wall of a building it is diverted upward with such velocity as to lift it above the flat roof of a building or the brow of the precipitous cliff. These also

may be so strong as to produce a difference of prèssure of two or three hundredths of an inch upon the same level. The greatest pressure will be in the wind on the brow of the cliff; while a few rods further back the air will be still and the pressure diminished according to the force of the wind.

Southerly winds are attended with falling barometer, because the superincumbent air becomes warmed and lighter. Northerly winds give opposite results.

Both "diurnal variation" and "annual variation" are not causes of variation, but curves of barometric pressure for a day or a year. They are the results of causes 1 and 2 affected by local geographic conditions.

Diurnal variation is a more or less regular rising and falling of the barometer during the twenty-four hours of a day. The barometer begins to rise as soon as the day breaks and continues to 10 o'clock a.m.; then it falls slowly until about 3 p.m.; then rising again to other culminations at 10 p.m., then falling again to about 2 a.m. These culminations may vary from 9 to 11 or from 2 to 4. The earlier time comes when the sun appears early, as in the summer time. This more or less regular rising and falling of the barometer is really due to the causes already enumerated, but it is well to remember the general form of the diurnal curve, as it is called. The diurnal curve will have wider range in the summertime than in the winter, and on sunshiny days rather than cloudy. A knowledge of this diurnal curve should be constantly kept in mind when reading the barometer or working up one's notices.

Annual variation. There is also a prominent curve for the year which is called annual variation. This is more pronounced where the difference in the seasons is greater. In tropical regions it is less pronounced and more regular.

These causes of variation are constantly active, and we need to make allowance for them in order to eliminate them from difference in pressure simply due to altitude.

INSTRUMENTAL ERRORS.

Delicate and sensitive instruments are usually kept stationary and under as uniform conditions as possible. This is impracticable in the use of the aneroid. Hence we will briefly mention a few sources of error under this head.

1. *Unequal heating of different parts.* This distorts the instrument and vitiates results incalculably. Larger instruments are especially subject to this trouble; hence they are rarely if ever used in the field. The most reliable size for general field use has a face of a diameter not less than 2½ inches and not more than 3½ inches.

2. *Misadjustment of the index.* If the index is correctly adjusted to its scale in altitudes from sea level up to 3,000 feet, one-hundredth of an inch would correspond to 9 feet on vertical scale, when the temperature is about 60° F. If it should be 10° below zero there should be a difference of 8 feet in altitude, or corresponding to one-hundredth of an inch; and temperature 120° above zero, 10 feet for one-hundredth of an inch. It is well because of this variation to test the instrument from time to time or compare the instrument with a known difference in altitude. This may be obtained by the comparison of the instrument at two stations whose altitudes are known, or in a building several stories high where careful measurements can be made.

3. *Friction at joints,* which requires a gentle tap to loosen the parts so they will respond freely to the hairspring.

4. *Tardy response of the instrument* to considerable and sudden differences of pressure, which may be due to slow resilience of the cylinder or main spring.

PERSONAL ERRORS.

These are similar to other cases which require close scrutiny and careful discrimination. As a rule, a more monotonous scale, like one marked in tenths and hundredths of an inch, is less easily read to hundredths than one marked in tenths and twentieths.

RULES FOR READING THE ANEROID FOR ASCERTAINING RELATIVE ALTITUDES.

1. Hold the instrument with its face horizontal and the eye of the reader over the center of the instrument.

2. If the wind is blowing, hold the instrument on the side half way between the windward and leeward points; or if the reading is taken on the windward side, it should be taken on the leeward side also, and each taken at its maximum.

3. Tap gently in order to overcome any stiffness of joints or weakness of hairspring.

4. If index is coarse, read on one side, preferably on the left side.

5. The hand should not touch the metal portion of the instrument when the reading is taken.

6. In reading it is customary to use a magnifying glass, and this distorts the image of the index. The index should always appear as a straight line when the reading is taken. As long as it appears curved it is not at the true reading.

7. In some instruments the index is so broad that it cannot be read very closely unless you take one side and make that the reading point. Of course the reading should always be upon the same side of the needle or index.

8. The instrument should always have the same vertical relation to the level recorded. It is well to form the habit of standing with the feet upon the level.

9. Care should be taken to prevent jolt or collision of the instrument with surrounding objects. It is well to have the instrument so fastened in the case that if dropped the metal portion should be kept from striking any solid object.

10. As to what to record, the following method has been found the most satisfactory: If your instrument has a scale of feet, have little or nothing to do with it. It is a trouble and apt to be a snare. Make constant use of your watch. Keep a record of the time of reading. A wrist watch is very helpful.

Check the record of readings as often as possible, at least two or three times a day. This may be done by reading a second time at any one station. The day's trip should be planned in such a way as to cross one's course several times. Of course the difference in reading at any one point will indicate the variation, due to weather conditions, of the instrument during that time, and this makes it necessary to read the time for every reading of the barometer. This will enable one to distribute the variations in the pressure of the air according to the time that has elapsed. We have considered many differ-

ent causes of variation, but really it is not important to know how much each of these may be in any particular case. We may assume that where the variation has two or three hundredths of an inch it has been in a nearly uniform direction, though it may have been a combination of several of these causes. Checking of the record may also be obtained by reading bench marks provided beforehand either at some point fixed by the survey or determined by railroads. Another easy means of checking, if near a large stream, is by taking readings at the surface of the water. A large stream is virtually horizontal; the slope of the Missouri river, for example, is less than a foot a mile. Of course a lake would be exactly horizontal.

CONCLUSIONS.

1. If these rules are carefully followed you may count on determining the difference in altitude between two points to be within 10 feet of correct; even to 5 feet if conditions are favorable.
2. By this means one can determine a slope of from 5 to 10 feet per mile.
3. The accuracy may be increased by the use of an automobile, which enables one to make readings at different points in very short time.
4. The aneroid is of special service, if not indispensable, in rough and timbered areas where few stations are in sight of one another.
5. It is particularly helpful in working out disturbed strata rapidly, and therefore most convenient for rapid reconnoisance of oil structures.

Archæological Notes on Pine River Valley, Colorado, and the Kayenta-Tuba Region, Arizona.

Albert B. Reagan.

The work on these areas covers the period from 1916 to 1920, as time would permit. For convenience, each region—Pine river, Kayenta, and Tuba—and the notes on same will be considered separately.

THE ANCIENT RUINS IN LOWER AND MIDDLE PINE RIVER VALLEY, COLORADO.

Pine river, a tributary of the San Juan, runs nearly north and south from about the south line of Colorado northward to the top of the San Juan range, at about a third the distance from Durango to Pagosa Springs. The stream is of rapid current and carries a large volume of water, enough to irrigate a much larger area than is now irrigated by it. The lower and middle inner valley, which is elevated but little above the stream, is usually not over half a mile wide. The first bench encircling this varies in width from a quarter to a half mile, and in elevation from twenty to forty feet. Surrounding this bench is the mesa country, which rises some sixty feet above the first bench and extends back on each side of the river to the mesa-mountains as a table-land country, the width varying greatly. The inner valley and first bench are composed of silt and cobbles. The mesa is adobe overlying cobblestones of the Durango glacial stage and occasional country rock, with knobs of country rock jotting above the plain here and there. Originally, large sagebrush covered the whole region, among which were scattered cedars and piñons.